TABLE OF CONTENTS

23.1 INTRODUCTION

This chapter is concerned with the design of a treated timber, Longitudinally Nailed Laminated Deck structure. This type of structure has a laminated wood deck, where the length of laminations is oriented in the direction of the span of the bridge. The laminated wood deck is joined together by successive railing of each lamination to the preceding one. Each lamination is set on edge and nailed wide face to wide face. The laminated deck is prefabricated at a plant in panels less than 2.3 m (7'-6") wide, and shipped to the bridge site. At the bridge site the panels are attached by passing a drive spike through a shiplap joint. The deck elements are treated prior to shipping.

Other types of timber bridges not discussed in this chapter include timber trusses, arches, box culverts, girders, glu-laminated girders and parallel chord timber bridges.

The Longitudinally Nailed Laminated Deck is one of the least complex bridge types to construct. It is composed of simple spans between each support. It has a superstructure composed of a single material which is easy to fabricate and install. A bituminous overlay is generally placed on top to provide a wearing surface. Its limitation lies in the practical range of span lengths for its application.

Timber bridges are aesthetically pleasing and blend well in natural surroundings. The timber bridge can be constructed in any weather, including cold and wet conditions, without detrimental effects. Timber bridges are resistant to the effects of deicing agents. The lighter weight of timber allows for easier fabrication and construction since smaller equipment can be used to lift the members into place. Timber bridges tend to deteriorate faster if subjected to high repetitions of heavy loads. Their cost effectiveness should also be evaluated for each site.

True "Deck" behavior can only be attained when plate behavior exists and this requires continuity between the individual elements making up the deck. Continuity between individual elements comprising the deck is obtained by nailing adjacent elements together. To assist in spreading applied loads transversely across the deck, a spreader beam is provided at span centers. Other methods used to provide transverse live load distribution include transverse prestressing and doweled connections.

The timber members are treated with a preservative. This will protect the timber against decay and insects, and it will also retard weathering and checking. The requirements for preservative treatments can be found in "State of Wisconsin Standard Specifications; Section 507".

23.2 DESIGN SPECIFICATIONS AND DATA

(1) Specifications

Refer to the design related material as presented in the following specifications:

State of Wisconsin
Standard Specification for Road and Bridge Construction

American Association of State Highway and Transportation Officials (AASHTO)

National Design Specifications - Wood Construction (N.D.S.)

Timber Construction Manual - (AITC)

(2) Allowable Stresses. (AASHTO-TABLE 13.2.1A & 2A)

Douglas Fir - Larch

The required allowable stresses for timber members in the superstructure are defined as follows:

Timber Rail Posts . . . . . F_b = 13.1 MPa (1.9 ksi)

. . . . . F_v (HORIZ) = 586 kPa (85 psi)

. . . . . F_c ($\perp$) = (per N.D.S.) 5.0 MPa (730 psi)

** (Specify "No Heartwood is Allowed" on plans) **

Glu-lam Railing (Dry Condition) . . . . . F_b = 16.5 MPa (2.4 ksi)

. . . . . F_v (HORIZ) = 1138 kPa (165 psi)

. . . . . F_c ($\perp$) = (per N.D.S.) 4.5 MPa (650 psi)

Floor Planks for Prefab Panels . . . . . F_b = 10.3 MPa (1.5 ksi)

. . . . . F_v (HORIZ) = 655 kPa (95 psi)

. . . . . F_c ($\perp$) = (per N.D.S.) 4.3 Mpa (625 psi)

. . . . . E = 12410 MPa (1800 ksi)

Other Timber Members (Spreader Beams, Wedges, Curbs, Scuppers, Spacer Block) . . . . . F_b = (per N.D.S.) 9.0 Mpa (1.3 ksi)

. . . . . F_v (HORIZ) = 586 kPa (85 psi)

. . . . . F_c ($\perp$) = (per N.D.S.) 4.3 MPa (625 psi)

(3) Structure Selection

Timber bridges are not recommended over streams where the Q(100) discharge provides a freeboard less than 600 mm (24"). They are also not recommended on highways where the A.D.T. is greater than 400 vehicles per day.

23.3 DESIGN APPROACH

(1) Design Procedure

A. Dead Load

| The timber deck dead load is computed by using a timber weight of 7.9 kN/m^3 (50 pcf). The wearing surface dead load is computed by using a weight of 23.6 kN/m^3 (150 pcf). A post-dead load of 1.0 kN/m^2 (20 psf) is to be included in all designs in order to accommodate a possible future wearing surface. All spans are analyzed and designed as simple spans.

B. Live Load Distribution

This criteria is presented in AASHTO Section 3 "Distribution of Wheel Loads on Timber Flooring". For timber structures with longitudinal flooring, the live load shall be considered a point loading in the direction of the span. Normal to the direction of the span, the wheel load shall be distributed the width of the tire plus twice the thickness of the floor. For width of tire, see AASHTO (Section 3.30).

C. Span Length

For longitudinal flooring the span shall be taken as the clear distance between supports plus one half the width of one support, but shall not exceed the clear span plus the floor thickness. For multi-span bridges, it is more economical to pick span lengths that are near the maximum length for a given deck thickness. For a (3) span 24 m (80') long bridge, (3) spans at 7.8 m, 8.4 m, 7.8 m (26', 28', 26') and a 350 mm (14") deck for all spans could be used. A span arrangement of 7.5 m, 9 m, 7.5 m (25', 30', 25') would still require a 350 mm deck for the middle span, but would allow a 300 mm (12") deck for the end spans.

D. Live Load and Impact (AASHTO Section 3.8)

Impact allowance shall not be applied to timber structures. All timber bridges are to be designed for MS18 (HS20) live load.

E. Deck Design

All spans are designed as simple spans. Check bending of deck sing size factor, if applicable. Also check horizontal shear and compression perpendicular to the grain. Calculate the required spacing of drive spikes at the ship-lap joint and check shear transfer between laminations. Refer to the design example that follows.

F. Railing Design

Refer to AASHTO Section 2.7 for Railing Requirements and also the example that follows.

G. Rating of Superstructure

Refer to AASHTO, "Manual for Maintenance Inspection of Bridges" and also the example that follows.

H. Deck Thickness vs. Effective Span Table:

Deck Thickness	(AASHTO 3.25.2.3) Effect. Span (L)*
250 mm (10”)	L = 5.1 m (17’)
300 mm (12”)	5.1 m < L = 7.5 m (25’)
350 mm (14”)	7.5 m < L = 9.0 m (30’)
400 mm (16”)	9.0 m < L = 10.8 m (36’)

* Includes effects of F.W.S.

23.4 DESIGN EXAMPLE

English Units are used in this Example.

A (2) span timber structure is used for this design example. Each span is designed as a simple span. The structure is designed for a future wearing surface of 20 pounds per square foot.

Structure Preliminary Data

Span Lengths:	30'-0", 30'-0" (Both simple)
Live Load:	HS20
Impact:	Not applicable
Initial Wearing Surface:	150 pounds/cu. ft. (2" Uniform Thick.)
Future Wearing Surface:	20 pounds/sq. ft.
Dead Load of Timber:	50 pounds/cu. ft.

Allowable Design Stresses

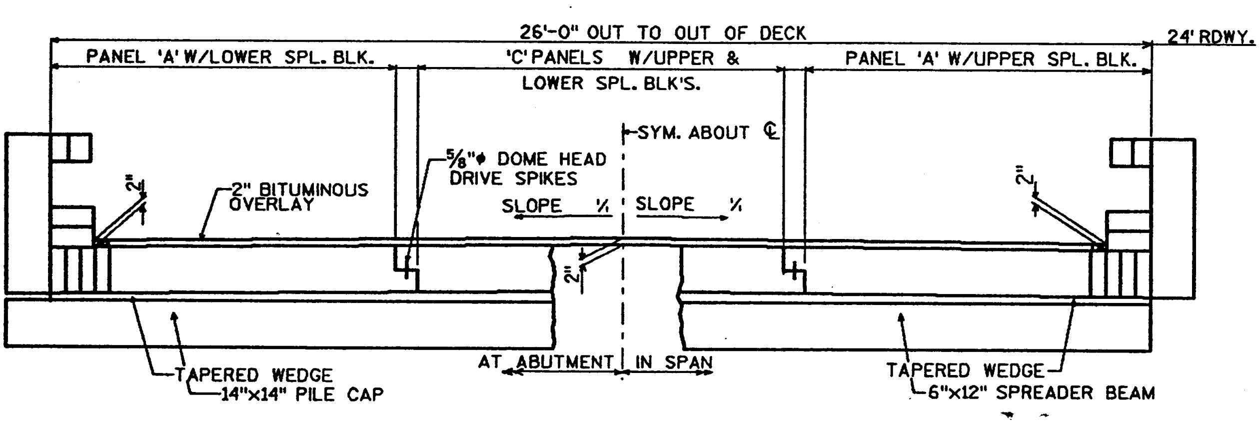
Floor Planks for Prefab Panels
Douglas Fir-Larch (AASHTO-Table 13.2.1A), (N.D.S.-Table 4A)

F_b = 1500 psi

F_v (HORIZ) = 95 psi

F_c ($\perp$) = 625 psi (per N.D.S.)

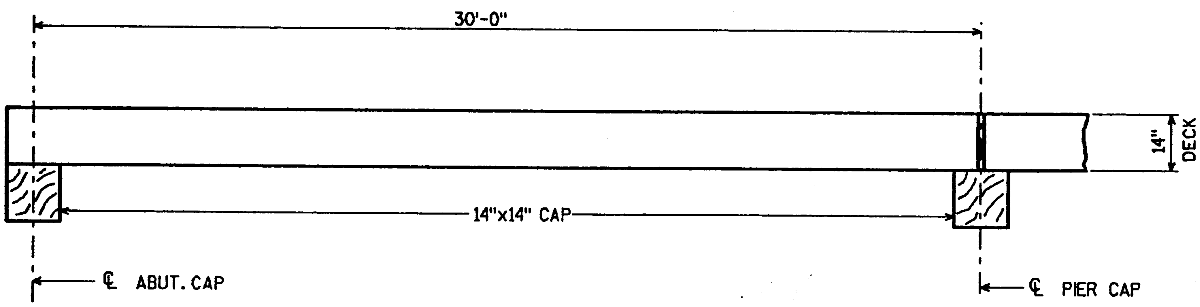
E = 1,800,000 psi



CROSS SECTION THRU ROADWAY

Effective Span

The effective span shall be taken as the clear distance between supports plus one half the width of one support, but not to exceed the clear span plus the floor thickness. Assume a deck depth of 14".



Span (effective) = (30'-0") - (7") - (7") + (7") = 29'-5" (controls)
Max. span (effective) = (30'-0") - (7") - (7") + (14") = 30'-0"

Wheel Load Distribution

In direction of the span, the wheel load shall be considered a point loading. Normal to the direction of the span, the wheel load shall be distributed over the width of the tire plus twice the thickness of the floor.

Width of tire = 20"

For a deck depth of 14", Dist. width = 20"+(2)(t)
= 20"+(2)(14") = 48"

Dead Load (on a 4.0 ft.-width)

Timber slab:	(1.17')(4.0')(50#/cu. ft.)	= 234#/FT.
Wearing Surface:	(4.0')(26#/sq. ft.)	= 104#/FT.
F.W.S.:	(4.0')(20#/sq. ft.)	= 80#/FT.

TOTAL D.L. = 418#/FT.

$$\text{Dead Load Moment} = \frac{WL^2}{8} = \frac{(418)(29.42)^2}{8} = 45{,}224 \text{ FT-\#}$$

Live Load: (on a 4.0 ft.-width)

HS20 (AASHTO - Appendix "A")

$$\text{Live Load Moment} = \frac{273.3 \text{ (ft.-k)}}{2} = 136.7\text{(ft.-k)}$$

Total Moment = D.L.+L.L. = 45,224 + 136,700 = 181,924 (ft.-#).

Section Modulus: (on a 4.0 ft. - width)

$$S = \frac{bd^2}{6} = \frac{(48")(14")^2}{6} = 1568 \text{ IN.}^3$$

Bending Stress:

Size Factor

$$C_F = (12/d)^{1/9}$$

where: C_F = Size Factor

d = Depth of Member in Inches

The size factor shall not apply to visually graded lumber 2" to 4" thick. (N.D.S.-Section 4.3.4) and (AITC Construction Manual, page 3-65). Therefore, this factor is not applied here.

$$f_b = \frac{M}{S} = \frac{(181{,}924)(12)}{(1568)} = 1392 \text{ psi} < 1500 \text{ psi (O.K.)}$$

Horizontal Shear Stress: (on a 1.0 ft.-width)

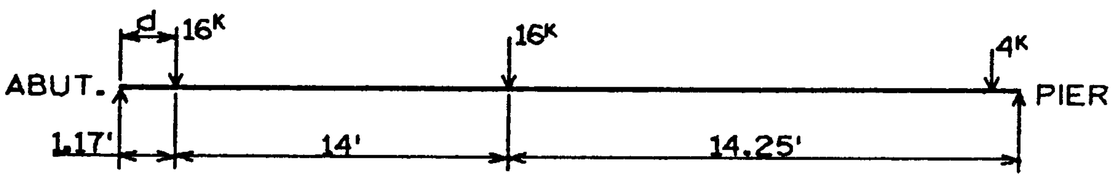
For (2) or more moving loads of about equal weight, loads shall be placed in the position that produces the largest shear force, V, neglecting any load within a distance from a support, equal to (d) depth of bending member. Wheel near right support has negligible effect.

Shear Location:

Check shear at (d) from left end of span.

(d) = depth of member = 1.17'

V_{DL} = (418 #/ft./4.0')(29.42'/2)-(1.17')(418 #/ft./4.0') = 1415#



$$V_{LL} = \frac{(16^{K.})}{(4.00')}\frac{(14.25')}{(29.42')} + \frac{(16^{K.})}{(4.00')}\frac{(28.25')}{(29.42')}$$

V_{LL} = $5.778^{K.}$ = 5,778#

Total (V) = $V_{DL} + V_{LL}$ = 1,415# + 5,778# = 7,193#

$$f_v = \frac{3}{2}\frac{V}{bd} = \frac{(7{,}193\#)(1.5)}{(12")(14")} = 64.2 \text{ psi} < 1.33 * 95 \text{ psi (O.K.)}$$

Where shear stress modification factor = 1.33, (N.D.S.-Table 4A-footnote 11).

It is unnecessary to compute or check the strength of wood bending members in cross-grain (vertical) shear as the member will always fail in along-the-grain (horizontal) shear before vertical shear. (N.D.S.-Section 3.4.1)

Compression Perpendicular to Grain (At Supports) (on a 1.0 ft.-width)

D.L. Reaction = (418#/ft./4.0')(29.42'/2) = 1,537#

L.L. Reaction (AASHTO-Appendix "A") $= \frac{49{,}100\#}{(2)(4.0')} = 6{,}138\#$

Total Reaction = DLR + LLR = 1,537# + 6,138# = 7,675#

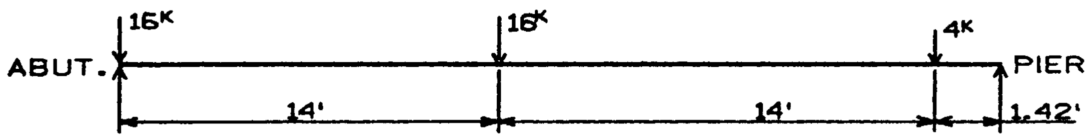
Allowable F_C ($\perp$) = 625 psi (per N.D.S.)

Req'd. Length of Bearing $= \frac{7{,}675\#}{(12")(625 \text{ psi})} = 1.0"$ (O.K.)

Check Spacing of Spikes at Ship-Lap Joint

(Based on Live Load only). Wearing surface and future wearing surface have a minimal effect in this example.

Place one wheel adjacent to Abutment.



Rea at Abut. $= \frac{(16^{k.})}{(4.0')} + \frac{(16^{k.})}{(4.0')}\frac{(15.42')}{(29.42')} + \frac{(4^{k.})}{(4.0')}\frac{(1.42')}{(29.42')}$

Distribution width (as shown on page 8) = 48"

Rea. = 6.15^k (for a 1.0' width).

For a 4" Plank, V = $6.15^{k.}$ (4/12) = $2.05^{k.}$ = 2,050#

f_v (horiz.) $= \frac{(3)}{2}\frac{V}{bd} = \frac{(1.5)(2{,}050\#)}{(4")(14")} = 54.9 \text{ psi} < 1.33*95 \text{ psi}$ (O.K.)

f_v (vert.) $= \frac{V}{bd} = \frac{2{,}050\#}{(4")(14")} = 36.6 \text{ psi}$

Check the horizontal shear at the plane of contact of the ship-lap joint, this is the neutral axis of the deck. The maximum shear occurs at this surface.

For a 4" wide joint:

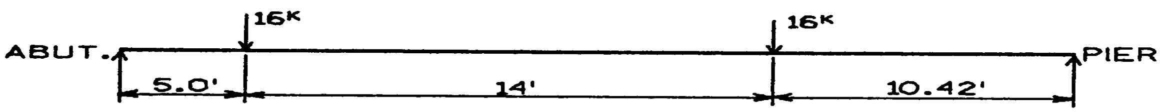
Shear per lineal foot of joint = (54.9 psi)(4")(12") = 2,635#/L.F.
5/8" diameter drive spikes are used at this joint.

Area of Spike = 0.306 $IN.^2$, Shear Strength = 20,000 psi

Single Shear Capacity of Spike = (0.306)(20,000) = 6,120#

Spike Spacing at ends of span = $\dfrac{6{,}120\#}{2{,}635\#/L.F.}$ = 2.3 = 27"

Place one wheel 5'-0" from abutment.



Shear at wheel location = $\dfrac{(16^{k.})}{(4.0')}\,\dfrac{(24.42')}{(29.42')} + \dfrac{(16^{k.})}{(4.0')}\,\dfrac{(10.42')}{(29.42')}$

Shear (v) = $4.74^{k.}$ (for a 1.0' width)

For a 4" plank, v = $4.74^{k.}$ (4/12) = 1.58^{k} = 1,580#

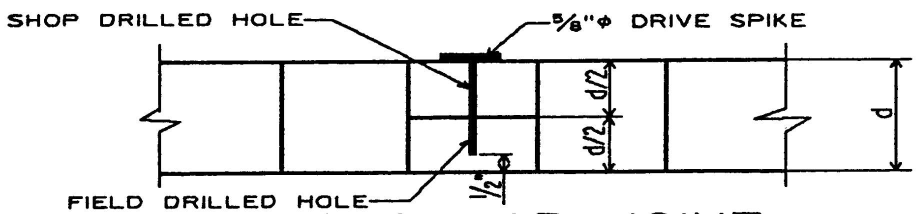
f_v (horiz.) = $\dfrac{3}{2}\,\dfrac{v}{bd} = \dfrac{(1.5)(1{,}580\#)}{(4")(14")}$ = 42.32 psi

Shear per lineal foot of joint = (42.32 psi)(4")(12") = 2,031#/L.F.

Spike spacing at 5'-0" from end = $\dfrac{6{,}120\#}{2{,}031\#/L.F.}$ = 3.01' = 36" > 24"

Use 24" as the maximum spacing

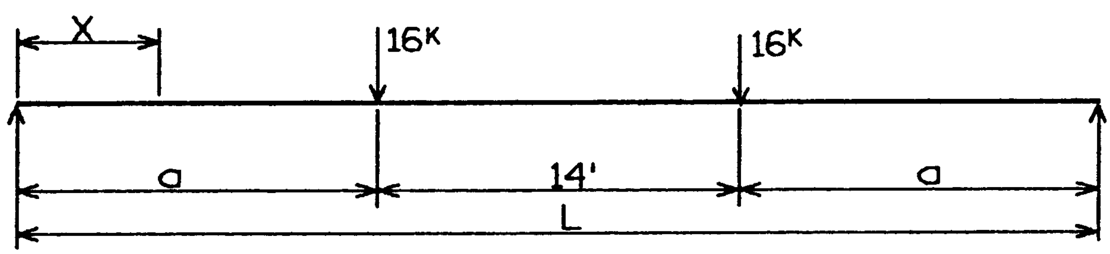
∴ Spacing of spikes for entire span along ship-lap joint = 24".



SHIP-LAP JOINT

Deflections

The "Timber Construction Manual" (AITC) recommends limiting the live load deflection to a value not exceeding (L/200 to L/300), while another reference suggests L/360.



$$\Delta\, C/L = \frac{P\,a}{6EI}(3LX-3X^2-a^2) = \frac{(64^{k.})(7.71')(12)^3}{6EI} \quad \frac{(3)(29.42)^2}{(2)} - 3(14.71)^2 - (7.71)^2$$

For (2) lanes, $P = 4\,(16^{k.}) = 64^{k.}$

$E = 1{,}800{,}000$ psi, X(midspan) = 14.71', a = 7.71', L = 29.42'

$$I = \frac{1}{12}bd^3 = \frac{(1)}{(12)}(26')(12")(14")^3 = 71{,}344\ \text{IN.}^3$$ (For entire bridge-width).

Δ C/L = 0.65"

L/360 = (29.42')(12)/360 = 0.98"

∴ Live load deflection is acceptable.

Ratings (w/o F.W.S.) (Working Stress).

Calculate ratings based on flexure at center of span. (on a 4.0 ft.-width).

Dead Load Moment $= \frac{WL^2}{8} = \frac{(338)(29.42)^2}{8} =$ 36,569 ft.-#.

Live Load Moment (shown earlier) = 136,700 ft.-#.

$f_{D.L.}$ = M/S = 36,569(12)/1568 = 280 psi

f_{LL} = 136,700(12)/1568 = 1046 psi

INV. RATING $= \frac{(F\ allow.)-(f_{DL})}{(f_{LL})}\ (20)$

INV. (FLEXURE) $= \frac{(1500\ psi) - (280\ psi)}{(1046\ psi)}\ (20) =$ HS23.3

OPER. RATING $= \frac{(F\ allow.)(1.33)-(f_{DL})}{(f_{LL})}\ (20)$

OPER. (FLEXURE) $= \frac{(1500\ psi)(1.33)-(280\ psi)}{(1046\ psi)}\ (20) =$ HS32.8

Calculate ratings based on shear at (d) from end of span. (on a 1.0 ft.-width).

V_{DL} = (338#/ft./4.0')(29.42/2)-1.17'(338#/ft./4.0') = 1144#

V_{LL} (shown earlier) = 5,778#

f_v (horiz.) D.L. $= \frac{3}{2}\ \frac{V_{DL}}{bd} = \frac{(1.5)(1144)}{(12")(14")} =$ 10.2 psi

f_v (horiz.) L.L. $= \frac{3}{2}\ \frac{V_{LL}}{bd} = \frac{(1.5)(5,778)}{(12")(14")} =$ 51.6 psi

Allow. F_V(Horiz.) = 1.33 * 95 psi 126 psi

Where shear stress modification factor = 1.33, (N.D.S.-Table 4A, footnote 11).

$$\text{INV. (SHEAR)} = \frac{(126\text{ psi})-(10.2\text{ psi})}{(51.6\text{ psi})}(20) = \text{HS}44.9$$

$$\text{OPER. (SHEAR)} = \frac{(126\text{ psi})(1.33)-(10.2\text{ psi})}{(51.6\text{ psi})}(20) = \text{HS}61.0$$

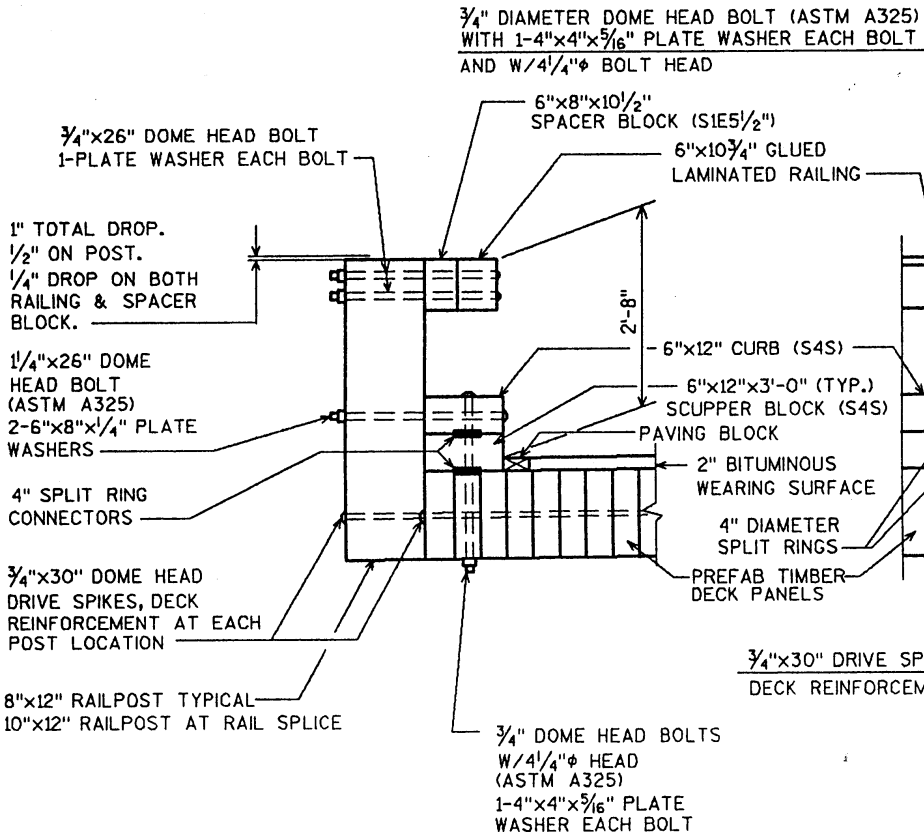
∴ <u>USE INV. RATING = HS23, OPER. RATING = HS32</u> (Flexure controls).

<u>Timber Bridge Railing</u>

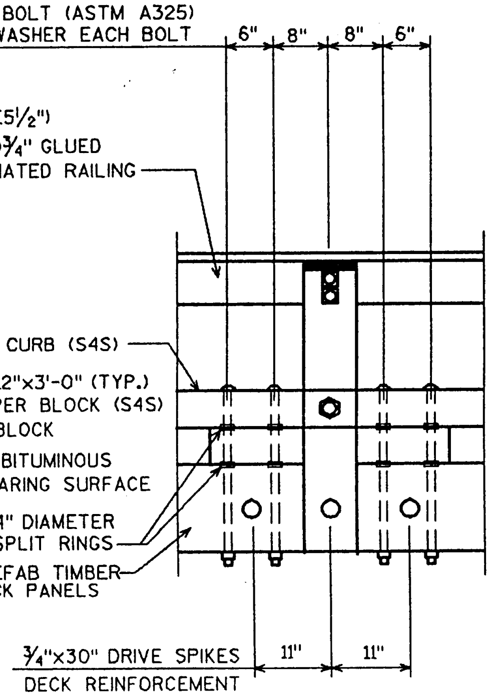
The Federal Highway Administration requires railing used on federally funded projects to be full scale crash tested.

Maximum rail post spacing is 6 feet.

Rail post to curb and curb to deck dome head bolts are to be made from ASTM A325 steel. All other hardware to be ASTM A307 steel.



SECTION AT RAILPOST



CURB AND SCUPPER DETAIL

REFERENCES

1. Wipf, T. J., "Load Distribution Criteria for Glued Laminated Longitudinal Timber Deck Highway Bridges", Engineering Research Institute, Iowa State University. 1985.

2. Transportation Research Board, "Timber Bridges", (Transportation Research Record #1053). 1989.

3. Forest Products Laboratory, "Design, Fabrication, Testing, and Installation of a Press-Lam Bridges", (Research Paper FPL-332) 1979.

4. AITC, "Modern Timber Highway Bridges, A State of the Art Report", (American Institute of Timber Construction, July 1, 1973).

5. Bohannan, Bill, "FLP Timber Bridge Deck Research," Journal of the Structural Division, ASCE, Vol. 98 No. ST3, Proc. Paper 8779, March, 1972, pp. 729-740.

6. Forest Products Laboratory, "Procedure for Design of Glued-Laminated Orthotropic Bridge Decks", (Research Paper FPL-210) 1973.

7. Forest Products Laboratory, "Erection Procedure for Glued-Laminated Timber Bridge Decks with Dowel Connectors", (Research Paper FPL-263) 1970.

8. Ou, Fong L., Ph.D., P.E., "An Overview of Timber Bridges", Engineering Staff Forest Service. (Transportation Research Board Paper-65th Annual Meeting) 1986.